FISHERIES DIVISION

TECHNICAL REPORT

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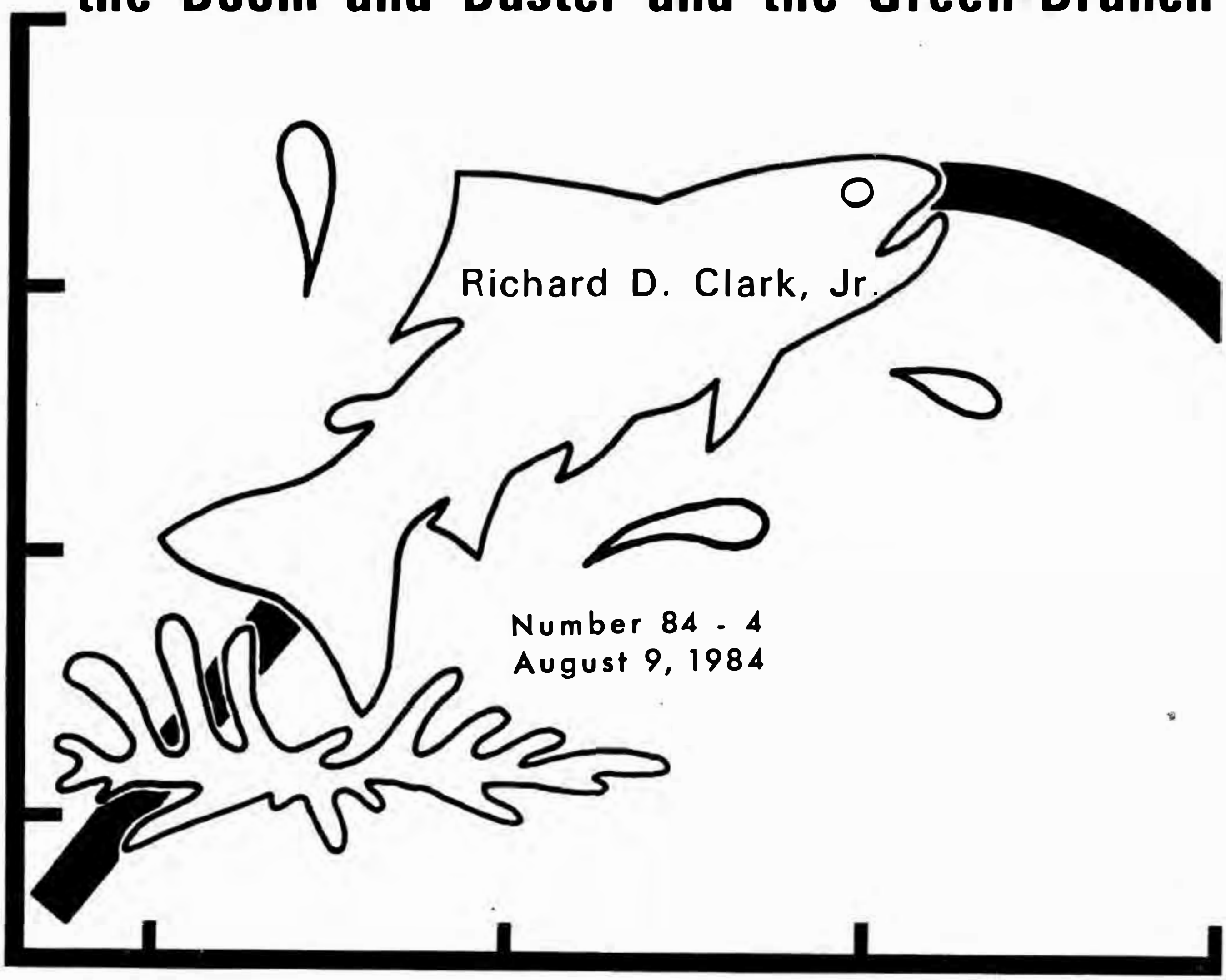

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Introduction

Lake whitefish populations support some of the most important commercial fisheries in the Great Lakes region. They are notorious for wide fluctuations in abundance and boom-and-bust fisheries. These fluctuations are a nuisance and economic hardship for commercial fishermen and are caused by factors which appear to occur at random, such as variable weather conditions at spawning time. Many fishermen, and even some biologists, think these fluctuations are unavoidable and uncontrollable facts of nature, but this is not entirely true. The ability of a whitefish population to resist unfavorable environmental conditions is reduced by exploitation. That is, a heavily fished population will fluctuate more than a lightly fished one, and these fluctuations are reflected in the commercial harvest. Also, the more severe these fluctuations are the greater the chances the fishery will collapse completely. Many such collapses occurred in the 1950's and 1960's. W. J. Christie, a well respected Canadian biologist, said in 1968, "The role of the biologists has been to write obituaries as various prime fish stocks have become history."

The goal of managing whitefish through annual catch quotas is to maintain the highest catch possible while avoiding the boom-and-bust fisheries of the past. One of our most difficult problems as fisheries biologists is to estimate the "ideal" exploitation rate which will accomplish this goal. It requires close monitoring of harvest and much biological research and analysis. Obviously, we cannot completely eliminate all fluctuations in whitefish harvest, but they can be reduced to the point where the fisheries will not collapse every 5 or 10 years. Thus, we should be able to eliminate severe peaks and depressions in the fishermen's income. One other important reason these collapses must be avoided is that they can lead to the local extinction of whitefish. History shows that whitefish stocks often recover from a population crash, but there are also examples in which they have not recovered.

As I said earlier, it is not easy to estimate the ideal exploitation rate for a whitefish fishery. It is a complex problem based partly in biology, partly in economics, and partly in sociology. However, I think our current estimates are getting very close to ideal in many areas of Michigan, and they will continue to improve as we continue to collect more information from commercial catches and other biological sampling programs. Annual catch quotas are based on these "ideal" exploitation rates and it benefits commercial fishermen in the long run if the quotas are not exceeded.

In general, historical records seem to indicate that whitefish fisheries are in serious danger of collapsing when exploitation (or some other mortality factor, such as sea lamprey predation) causes the mortality of adult fish to exceed 70% per year. The populations often last 5 or 10 years at these high mortality rates but eventually something (like bad weather) reduces reproductive success and causes failure of a year class. This often leads to a population crash and the collapse of the fishery. Regulating mesh size of fishing nets or imposing minimum size limits can help in these cases, but the primary need is simply to reduce the fishing effort so more fish can survive to reproduce. It is interesting to note that year-class failures are fairly common in whitefish populations, but when mortality rates of adult fish are lower, say around 60% per year, they cause only moderate reductions in stock abundance and do not cause fisheries to collapse. Thus, in general, the ideal exploitation rate for whitefish appears to be one which causes total mortality of adult fish to be in the neighborhood of 60% . This allows a substantial harvest and keeps mortality rate safely below the danger level of 70%. You should realize, however, that natural mortality, growth, and reproductive rates of whitefish vary from one geographical location to the next and data must be collected from each area stock to pin-point the exact exploitation rate which is best for that area.

The Boom-and-Buster and the Green-Branch

To illustrate how high exploitation rates can cause boom-and-bust fisheries, I will give two hypothetical, but realistic, examples of whitefish fisheries. The first will have a total mortality rate of 80% and I will call it the <u>boom-and-buster fishery.</u> The second will have a total mortality rate of 60% and I will call it the <u>green-branch fishery.</u> As you know, a green branch will bend in the wind but will not break, and this symbolizes the idea that this fishery will fluctuate to some extent but not collapse.

To make things easier for comparisons, I will give both boom-and-buster and green-branch whitefish the same natural mortality (death by causes other than fishing), growth, and reproductive rates. Thus, the higher total mortality rate of the boom-and-buster will be due entirely to higher exploitation from fishermen. This is because exploitation generally adds to natural mortality to increase the total mortality rate of a fish population. To keep things simple, I will assume all fish over 4 years old are fully vulnerable to the fishing gear. The natural mortality rate will be 36%, or in other words, 36% of the adult fish would die every year even if no fishing occurred. The average lengths and weights of fish of each age will be:

Age	4	5	6	7	8	9	10
Length (inches)	17.0	18.9	21.0	22.7	24.1	25.3	26.3
Weight (pounds)	1.6	2.5	3.6	4.6	5.7	6.7	7.6

Also, to get an idea of how reproduction is affected, I will assume half the fish are females and that 38% of these female fish are sexually mature and capable of reproducing by age 4, 56% of the females are mature by age 5, 81% by age 6, 90% by age 7, 94% by age 8, and 100% by age 9. Furthermore, I will assume that each mature female carries 8,100 eggs for each pound of her weight (thus, a 3-pound female would be capable of spawning 24,300 eggs).

Before comparing the boom-and-buster to the green-branch, I should mention that the above data may be hypothetical but they do come very close to describing the real whitefish populations in northern Lakes Michigan and Huron. Therefore, I would expect fisheries in those areas to behave either as boom-and-busters or green-branches depending on their exploitation rates.

The age structure of a fishery is defined by the total annual mortality rate of the adults and by the level of success of each year's reproduction. For the sake of argument, I will begin by assuming reproduction produces a constant number of young each year and that 1,000 of the young survive to age 4. Of course we know this assumption is unrealistic for whitefish because their reproductive success is highly variable, but I will make the assumption now so we can first concentrate on the effects of the total mortality rate. Given 1,000 fish at age 4, it is not difficult to calculate how many of them will survive to each succeeding age. The annual survival rates are 100% - 80% = 20% for the boom-and-buster and 100% - 60% = 40% for the green-branch. Thus, by age 5 there are 1,000 x 0.20 = 200 fish still alive in the boom-and-buster and 1,000 x 0.40 = 400 fish still alive in the green-branch, and so on. It is somewhat more difficult to calculate how many of the 1,000 fish would be caught each year and how many would die natural deaths, but by following well accepted biological formulas we can do it. We can calculate other things also, such as the weight of the fish harvested and how many eggs the surviving females in the population are capable of spawning in a given year. I made all these calculations for both fisheries and the results are listed in Tables 1 and 2.

There are many important differences in these two fisheries. For one thing, the boom-and-buster produces a larger total harvest -- 743 pounds per year versus 624 pounds per year in the green-branch. This is not very surprising because I said earlier that the exploitation rate would be higher in the boom-and-buster. The exploitation rates can be calculated by dividing the total number harvested by the total number in the population and then multiplying by 100 to change the result to a percentage rate. For the boom-and-buster this gives 57.6%, and for the green-branch this gives 30.5%. Therefore, the exploitation rate in the boom-and-buster is nearly twice as high as that of the green-branch. Because fishing effort is roughly proportional to exploitation rate, this means that almost twice as much fishing effort is being spent on the boom-and-buster fishery for only a slight increase in harvest. It also means that the fishermen of the boom-and-buster only get about half as many fish per net lift as the fishermen of the green-branch.

Another thing to notice is the effect this extra exploitation has on the fish population in the boom-and-buster fishery. There are fewer fish in total than in the green-branch, 1,248 versus 1,664, and more importantly, the population in the boom-and-buster has only four age groups (4 to 7) while the green-branch has seven (4 to 10). The reason, of course, is that the fish of the boom-and-buster are caught by fishermen before they reach an old age. It is this reduction in the number of age groups that leads to wide fluctuations and eventual collapse. I will explain more about this later.

The potential egg production of the two fisheries is also very different. The green-branch population is capable of producing four times as many eggs each year as the boom-

Table 1. The boom-and-buster fishery.

Age	Number of fish in population	Number harvested each year	Weight of harvest (pounds)	Potential egg production (thousands)
4	1,000	576	530	630
5	200	115	159	279
6	40	23	43	109
7	8	5	11	31
Totals	1,248	719	743	1,049

Table 2. The green-branch fishery.

Age	Number of fish in population	Number harvested each year	Weight of harvest (pounds)	Potential egg production (thousands)
4	1,000	305	281	1,259
5	400	122	169	1,114
6	160	49	91	872
7	64	20	46	488
8	26	8	22	244
9	10	3	10	114
10	4	1	5	54
Totals	1,664	508	624	4,145

and-buster population (4,145,000 eggs versus 1,049,000 eggs). In fact, either the age-4 fish or age-5 fish of the green-branch taken alone could produce more eggs than the entire boom-and-buster population. Age-4 green-branch fish could produce 1,259,000 eggs and age-5 fish could produce 1,114,000 eggs. You might be wondering why the same number of fish starting at age 4 (1,000) in the boom-and-buster produces only 630,000 eggs. I have taken into account the fact that whitefish spawn in the fall of the year and that the fishermen will catch and remove most of their harvest before the fish can spawn.

The reduced egg producing capacity is another thing that can lead to wide fluctuations in the boom-and-buster fishery. For example, a stretch of unusually cold weather in the spring can cause many newly born whitefish to die. Let us say this does happen to our two fisheries and it causes 70% of the young fish to die. First, if all the eggs were deposited by the females and 10% of them are fertilized and survive to hatching, then there would be 104,900 newly born whitefish in the boom-and-buster fishery right before this disastrous cold weather hits. Under the same assumptions there would be 414,500 newly born fish produced in the green-branch fishery. When the cold weather kills 70% of the young, this leaves 31,470 young in the boom-and-buster population and 124,350 young in the green-branch population. Notice that even after the cold weather hits there are more young whitefish left in the green-branch population than were originally present in the boom-and-buster population (124,350 versus 104,900).

The 31,470 young in the boom-and-buster population will probably have better-than-average survival to age 4. This is due in part to the fact that there are fewer other whitefish to compete with them for food and other necessities of life. Biologists call this phenomenon density-dependent survival, that is, a higher percentage of young usually survive in a year when their numbers are lower at the start of the year. This also has lead to the fisherman's saying, "The harder you fish them, the more of them there are." However, there are upper limits to this improved survival, and it is very unlikely that 1,000 of the 31,470 boom-and-buster young would survive to age 4. More likely, there would be fewer than 1,000 left and this will cause a reduction in the fishermen's catch for several years while this age group passes through the fishery.

Now consider what would happen to these two fisheries if a more serious disaster occurred and reproduction was a complete failure in some year. It is not unusual for real whitefish populations to have complete or near-complete loss of a year class. In the year our lost year class would have been 4 years old, the total population size for the boom-and-buster would only be 248 fish (1,248 total fish minus 1,000 age-4 fish), and the fishermen would only harvest 213 pounds of fish (743 pounds minus 530 pounds of age-4 fish). Furthermore, only 419,000 eggs would be produced that fall (1,049,000 minus 630,000 eggs produced by age 4's). Obviously, these would be very severe reductions for both fishermen and fish to absorb, and if by chance a series of two or more of these bad year classes occurred, it would probably put the fishermen out of business and may cause the whitefish population to be destroyed. A similar disaster in the green-branch fishery would not be nearly so severe. The loss of age-4 fish would result in 664 fish remaining in the population, 343 pounds harvested, and 2,886,000 eggs produced (still plenty of eggs to produce a good year class in the future).

These hypothetical examples illustrate why whitefish fisheries with high exploitation rates fluctuate more than those with lower exploitation rates. An important point to remember is that the more a fishery fluctuates, the better the chances it will collapse. Therefore, over the long run, a whitefish fishery that is managed so total mortality is around 60% (like in our green-branch example) will produce a much more consistent annual harvest and is a more desirable kind of fishery.

Real World Examples

Enough biological theory. Now I will give some real world examples of whitefish fisheries that have behaved like boom-and-busters or green-branches.

Whitefish of Lake Ontario, a boom-and-buster that collapsed and never recovered

First, I will describe the Canadian whitefish fishery in Lake Ontario. My information about this fishery came from several reports published by W. J. Christie (see reference list). During the 1940's whitefish in Canadian waters of Lake Ontario produced a fairly stable yield averaging 320,000 pounds per year. I estimated the total mortality of adult fish during this period from Christie's data and determined that 39% of the adult fish were dying per year (a green-branch fishery). Two important changes occurred in the fishery about 1950. First, the efficiency of the fishermen improved with the conversion from cotton and linen to nylon gill netting. Second, the government started a less restrictive management policy because they wanted to improve the economic conditions of the fishermen, and they thought the fish stocks could take more fishing pressure. After these changes, the average yield during the 1950's increased slightly to 343,100 pounds per year, but this caused the total mortality rate to increase greatly; it averaged 77% from 1955 to 1960 (a boom-and-buster fishery). The fishery was still going strong in 1963 with a harvest of 354,000 pounds brought to dockside, but Christie wrote in that year, "It is felt that this stock must be considered seriously overfished....It has been shown that the increased fishing pressure of recent years did not produce more fish, but rather about the same number of smaller fish with an increased year-to-year variation...the failure of two or more year classes could be expected to have a drastic effect."

In 1968 he wrote, "The Lake Ontario whitefish population is a good example of an over-exploited fish stock." By that time the fishery had essentially collapsed. Fishermen harvested only 47,000 pounds in 1967. It continued to decline without recovering. Fishermen only caught 4,000 pounds of whitefish in 1976.

The whitefish fishery of Lake Winnipeg, a boom-and-buster that was transformed into a green-branch

Another example with a happier ending is the case of the whitefish of Lake Winnipeg, Manitoba, Canada. My information from this fishery comes from biologist E. B. Davidoff of Manitoba (see reference list). The first records of commercial catch from Lake Winnipeg date back to 1883. For over 50 years the lake produced an average of 3,000,000 pounds of whitefish annually, but in about 1950 fishermen switched from cotton to nylon gill netting and fishing regulations became less restrictive (the same thing that happened in Lake Ontario). To give you an idea of the effect this had, the total mortality rate of adult fish went from 66% in the 1940's to 88% in the 1960's. The harvest averaged 1,650,000 pounds in the 1940's and only 969,600 pounds in the 1960's.

Biologists began to worry about this decline in harvest. They described the trend in the fishery as one with fluctuating and diminishing harvest and increasing fishing effort. The pattern of fish production from the lake was boom or bust. They warned that fishing effort in the lake must be reduced to prevent a total collapse of the fishery. Finally, in 1970 the commercial fishery was closed, not as a result of any fishery management decision but because of mercury pollution. The fish were contaminated and could not be sold. This closure only lasted 1 year but it gave the whitefish population a chance to begin a recovery.

When the fishery re-opened in 1971 a quota system was developed to control the harvest. The objectives of the quotas were:

(1) To conserve fish stocks and eliminate severe peaks and depressions in catch and income by spreading the benefits of good year classes over a period of several years.

(2) To maintain optimum sustainable fish population levels, and optimize fishermen's income.

(3) To increase the number of major age groups and number of spawners in the whitefish population.

This quota system was a great success in Lake Winnipeg. Total annual mortality of whitefish decreased from 88% in the 1960's to only 47% in the 1970's. In other words, the fishery was transformed from a boom-and-buster to a green-branch. Quotas and harvests gradually increased. The harvest went from 571,200 pounds in 1969 (before the quota system) to 1,240,800 pounds in 1977. Also, because whitefish were surviving to older ages, the average size and weight of a fish in the catch increased. This brought more dollars to commercial fishermen because large fish were worth more money than small fish. Davidoff concluded that this success story proves that applied biological research and management can restore an ailing fishery so as to increase and maintain sustainable harvest and fishermen's income.

Conclusions

(1) Fluctuations in abundance and harvest of whitefish are made worse and worse as exploitation and the total mortality rate of adult fish increases.

(2) The more a fishery fluctuates the better the chances are it will collapse.

(3) Based on historical examples, it seems that whitefish fisheries display dangerously severe fluctuations and are in serious danger of collapsing when 70% or more of the adult fish are killed each year.

(4) Whitefish populations do not always recover after a collapse so over-fishing could lead to extinction of the species in some areas.

(5) The goal of managing whitefish through annual catch quotas is to maintain the highest catches possible that will reduce the severity of annual fluctuations and prevent stock collapse. It appears that a quota which keeps the total mortality of adult fish safely below 70% may be ideal in many areas.

(6) It has been demonstrated that an ailing fishery can be improved by developing a scientifically based quota system.

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